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# Assessing sub-regional water scarcity using the groundwater footprint

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ABSTRACT

The groundwater footprint (*GF*) is an innovative concept that is used to evaluate groundwater sustainability, and it can be defined as the area required to sustain groundwater use and groundwater-dependent ecosystem services in a region. In this study, we evaluated water scarcity on a sub-regional scale using a water stress indicator defined as the ratio of groundwater footprint to aquifer area *GF/A* that indicates the sustainability of the aquifers. The higher the stress indicator is, the less sustainable the aquifer is. This study was conducted in the northern part of Colombia; it involves 19 municipalities located in the Sucre department and six main aquifers. Through the use of 5000 interviews, the study calculates water abstractions in the study area, such as cattle, commerce, industry, homes, agro-industry and agriculture; however, only domestic demand associated with groundwater fed aqueducts and groundwater wells was considered because it represents almost 80% of the total abstractions. In addition, the study considered climate change and population growth and how they may affect the *GF*. The analysis shows that the water stress indicator for the Morroa aquifer has the highest groundwater stress among the six aquifers subject to investigation. GF is considerably higher than many of the world aquifers. Using the same indicator, we compared different mitigation alternatives to increase the sustainability of the Morroa aquifer. Results show that a combination of artificial recharge measures with an alternative source able to supply at least 50% of the domestic consumption appears to be the best choice to make the aquifer more sustainable. *GF* is a simplified yet robust way to support decision-makers and stakeholders so as they can evaluate water management policies and strategies.

## 1. Introduction

In the last few years, the demand for groundwater has increased considerably to be able to supply the needs of economic sectors and domestic use. At world level and in proportions that vary widely from one country to the next, especially in those regions where there is no surface water and groundwater is the only source, groundwater exploitation covers approximately: 40% for industrial activities; 20% for irrigation and 40% for drinking water needs (Zektser and Lorne, 2004). The high demand of this resource and the lack of proper management strategies have generated some concerns around a possible scarcity of groundwater in certain regions due to an accelerated decrease in water levels (Zektser and Lorne, 2004; Wada et al., 2010; Rodell et al., 2009; Konikow and Kendy, 2005).

A novel indicator used to study sustainability, vulnerability and stress of aquifers is the groundwater footprint concept- GF (Gleeson and Wada, 2013). The GF determines the volume of water that is required for a consumer or producer, also known as blue water (Aldaya et al., 2012), without taking into account the surface water. It is used to estimate groundwater stress and was introduced for the first time by Gleeson et al. (2012). Groundwater stress is an indicator of water scarcity, calculated as the ratio of the groundwater footprint and aquifer area. The aforementioned indicator focuses on groundwater quantity and ignores the resourcés possible contamination problems, which may result in a smaller water footprint and stress.

There are well-documented studies of the largest global aquifers' water footprint and scarcity (e.g. Gleeson and Wada, 2013; Gleeson et al., 2012; Hoekstra et al., 2012) that help to classify those regions with an elevated water stress, either by the characteristics of the environment or the overexploitation of the resource. Colombia has a low groundwater footprint in the majority of its territory (Hoekstra et al., 2012); however, on a sub-regional or local-level, the situation may be different but there is not enough evidence in the literature.

This is the case of the aquifer system that is located in the Sucre

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department, found in the north of the country, where small creeks represent the main water surface bodies but run dry several months of the year; hence, major source of supply is groundwater. Besides, the groundwater abstractions in the region, which are mostly for domestic use, are not fully controlled by the environmental entities, as the exploitation areas are very large. Every year the National Water Study shows the condition and dynamics of the water in Colombia (VYDT, 2014); however, the study does not establish a clear division between surface and groundwater footprint. Moreover, the analysis undertaken of hydrogeological zones is more on a national than a sub-regional or local scale. For this reason, it is necessary to assess the current conditions of the aquifers and establish if the levels of water use could lead to water shortages and ecological damage in the short and long term. We believe that the groundwater footprint and groundwater stress indicators, calculated in a spatial way, will provide a more reliable and accurate overview of the situation in Sucre and will be a useful tool for the decision makers to implement suitable water management strategies. In this respect, the main goal of the research is to investigate the applicability of the groundwater footprint concept in a sub-regional level to define water scarcity and design measures to improve sustainability.

## 2. Characteristics of the study area

The study area is located in the Sucre department in the north of Colombia, which is a part of the Caribbean region. This department hydrography is composed by a perennial natural network of rivers and marshes located in the southern part (Fig. 1).

Conversely, in the northern part rivers run dry most of the year. The six main aquifers of the Sucre department located within 19 of the 26 municipalities that conform the department represent an area of 5000 $km^2$ approximately (Fig. 2a). This area has an alternate wet and

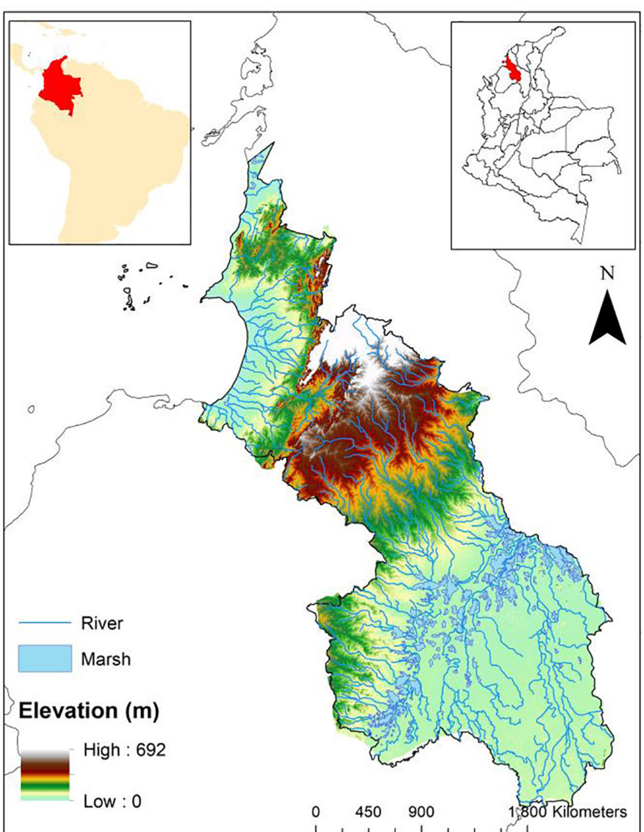


**Fig. 1.** Sucre Department: River Network and Digital Elevation Model (DEM).

dry season, the driest months being from December to March and the rainiest from May to October. April and November are transition months, however most part of the year, specifically during the dry season and the transition months, the surface water streams disappear due to the high temperatures reaching 34 °C and an average temperature of 28 °C.

Additionally, in most of the region, the climate may be classified as tropical savanna, with a moderate to high precipitation between 1000 and 1800 mm and a high evapotranspiration (1400–1600 mm), estimated by the Institute of Meteorological, Hydrological and Environmental Studies (IDEAM) with an evaporation tank and empiric equations. Agricultural and livestock activities that take place in the zone supply their necessities mainly through rainwater reservoirs. In this sense, for the other activities, other sources of water such as groundwater are necessary to ensure a continuous supply of water. Therefore, for domestic use and drinking water, the community uses mainly aqueduct systems supplied by groundwater.

Sucre has outcrop sedimentary rocks and unconsolidated sediments with a marine, transitional and continental origin, the ages of the formations range from the upper cretaceous to quaternary epochs. The study focuses on six aquifers identified in Sucre (Colombia). Fig. 2b presents the main aquifers within the study area and Table 1 the corresponding area and municipalities within each of them.

The Morroa aquifer is the biggest of the six aquifers that comprise the system with an area of around 1000 $Km^2$ (Pérez-García et al., 2009, 2014). It supplies a population that is close to 400,000 inhabitants (National Administrative Department of Statistics-DANE, 2015) located in the municipalities of Corozal, Ovejas, Los Palmitos, Morroa, Sincelejo and Sampués (Corporacion Autonoma Regional de Sucre, 2005). Only Corozal, Morroa, Sincelejo and Sampués have a central aqueduct (Salazar et al., 2011). Main streams within the study area are the *Arroyo Grande de Corozal* and the *Arroyo Morroa*; both run over the Morroa aquifer recharge area, but only the Arroyo Grande de Corozal remains during the dry season as it is mainly fed by return water from Sincelejo urban center.

The Morrosquillo aquifer is located in the southern Colombian Caribbean basin and supplies a population that has close to 100,000 inhabitants from the municipalities of San Onofre, Santiago de Tolú and Coveñas (National Administrative Department of Statistics (DANE), 2015). The first two municipalities have a central aqueduct while in the other municipality water is supplied mainly from artisanal extraction wells and rainwater collectors (Wada et al., 2010). The resource is supplied by around 800 wells (Corporacion Autonoma Regional de Sucre, 2005), of which less than 1% have been legalized (Corporacion Autonoma Regional de Sucre, 2005) and, on average, 80% is utilized for human supply (Corporacion Autonoma Regional de Sucre, 2005).

Other aquifers have been reported in the literature associated with the study area. In particular, the Betulia, Toluviejo, San Cayetano and El Roble aquifers have been identified as groundwater bodies in a study carried out by the Regional Environmental Authority (Corporacion Autonoma Regional de Sucre, 2005); however, there is scarce available information on these formations in the literature.

The Betulia aquifer is thought to supply water to a population of close to 92,000 inhabitants (National Administrative Department of Statistics (DANE), 2015) from the municipalities of Buenavista, Galeras, San Juan de Betulia, San Pedro and Since. Toluviejo and San Cayetano appear to supply around 82,000 inhabitants living in the municipalities of Palmito, Toluviejo and San Onofre while El Roble appears to supply the municipality of El Roble (10,000 inhabitants).

The purpose of this study is to evaluate water scarcity on a sub-regional scale using a water stress indicator that is based on the concept of a groundwater footprint. Additionally, we aim to assess the suitability of this indicator in the design of policies and water management strategies in order to ensure the sustainability of the water supply and reduce the pressure of local aquifer systems. The study focuses on six aquifers identified in Sucre (Colombia).